

DATA COMPRESSION APPLIED TO HHVT

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The High Resolution, High Frame Rate Video Technology (HHVT) project engineers wrote a task order to Analex Corporation to study data compression techniques that could be applied to the HHVT system. Specifically, the goals of the HHVT data compression study are to accomplish the following:

- (1) Determine the downlink capabilities of the Space Shuttle and Space Station Freedom to support HHVT data (i.e., determine the maximum data rates and link availability)
- (2) Determine current and projected capabilities of high speed storage media to support HHVT data by determining their maximum data acquisition/transmission rates and volumes
- (3) Identify which experiments in the HHVT Users' Requirements database need data compression, based on the experiments' imaging requirements
- (4) Select the best data compression technique for each of these users by identifying a technique that provides compression but minimizes distortion
- (5) Investigate state-of-the-art technologies for possible implementation of selected data compression techniques

Data compression will be needed because of the high data rates and large volumes of data that will result from the use of digitized video onboard the Space Shuttle and Space Station Freedom. For example, the data rates and volumes stemming from the use of standard RGB video and HHVT RGB video are compared in the following table:

	Standard RGB Video	HHVT RGB Video
Spatial resolution, pixels	512 x 512	1024 x 1024
Color components	3 (Red, green, blue)	3 (Red, green, blue)
Quantization, levels (8 bits)/component	256	256
Frame rate, frames/sec	30 (interlaced scan)	1000 (no interlacing)
Duration, frames	10 000	10 000
Resultant data rate	190 Mbits/sec	26 Gbits/sec
Required storage volume, Gbits	63	520

Existing high speed data storage systems and those expected to be commercially available within the next few years cannot support the very high data rates that are generated by some potential users of the HHVT system. Many of these experiments will require data compression during their data acquisition cycles just to be compatible with existing data storage devices.

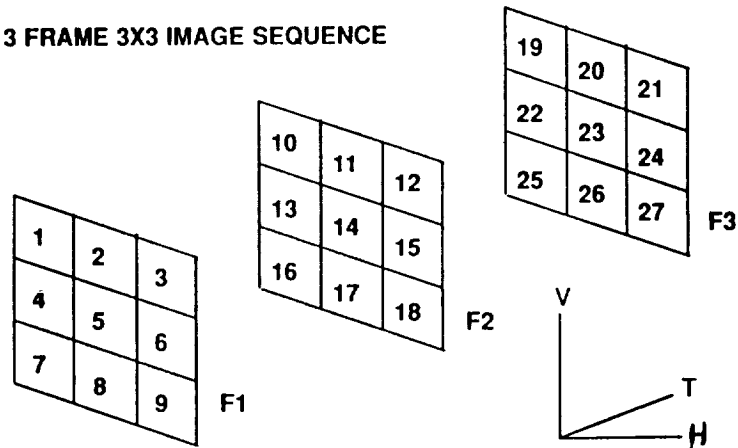
The downlink capabilities of the Space Shuttle and Space Station Freedom cannot support the large volumes of HHVT data due to limited link availability. For example, the link will be available to the USLab on Space Station Freedom for 74 min/orbit. With a maximum downlink rate of 75 Mbits/sec, the maximum volume of data that can be downlinked per orbit is 333 Gbits. Assuming the data must be downlinked before the next orbit, data compression needs to be applied after the data has been acquired but prior to downlink. Nonreal-time processing could be used since the data is not necessarily required immediately after it has been acquired.

II. THEORETICAL APPROACHES TO DATA COMPRESSION

• **FIRST GENERATION APPROACH**

- BASED ON INFORMATION THEORY AND STATISTICS
- IMAGES TREATED AS 2-D OR 3-D RANDOM FIELDS (V,H,T)
- EXPLOITS CORRELATION OF A PEL WITH ITS SPATIAL AND TEMPORAL NEIGHBORS

3 FRAME 3X3 IMAGE SEQUENCE



- DATA COMPRESSION BY STATISTICAL REDUNDANCY REDUCTION

II. THEORETICAL APPROACHES TO DATA COMPRESSION

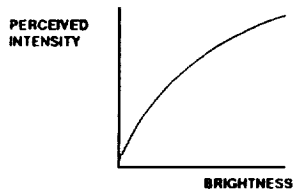
• **FIRST GENERATION APPROACH**

- CORRELATION BETWEEN PELS DECREASES WITH INCREASING SPATIAL OR TEMPORAL DISTANCE BETWEEN PELS
- CAUSAL APPROACHES ONLY REDUCE CORRELATION OF PEL 14 WITH PELS 1-13 SINCE PELS 1-13 ARE SCANNED PRIOR TO PEL 14
- INTRAFRAME APPROACHES ONLY REDUCE CORRELATION OF PEL 14 WITH OTHER PELS IN F2
- ADAPTIVE TECHNIQUES VARY THEIR CODING EFFICIENCY BASED ON SCENE ACTIVITY

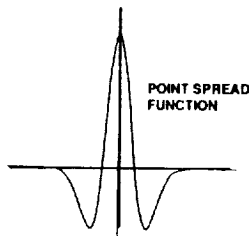
II. THEORETICAL APPROACHES TO DATA COMPRESSION

• **SECOND GENERATION APPROACH**

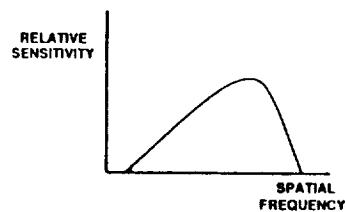
- EXTENDS INFORMATION THEORY TO INCLUDE VISION AND IMAGE GATHERING MODELS
- MOST IMPORTANT INFORMATION IS EXTRACTED FROM THE IMAGE
- INSPIRED BY PROPERTIES OF THE HUMAN VISUAL SYSTEM (HVS)



1. WEBER'S LAW



2. LATERAL INHIBITION



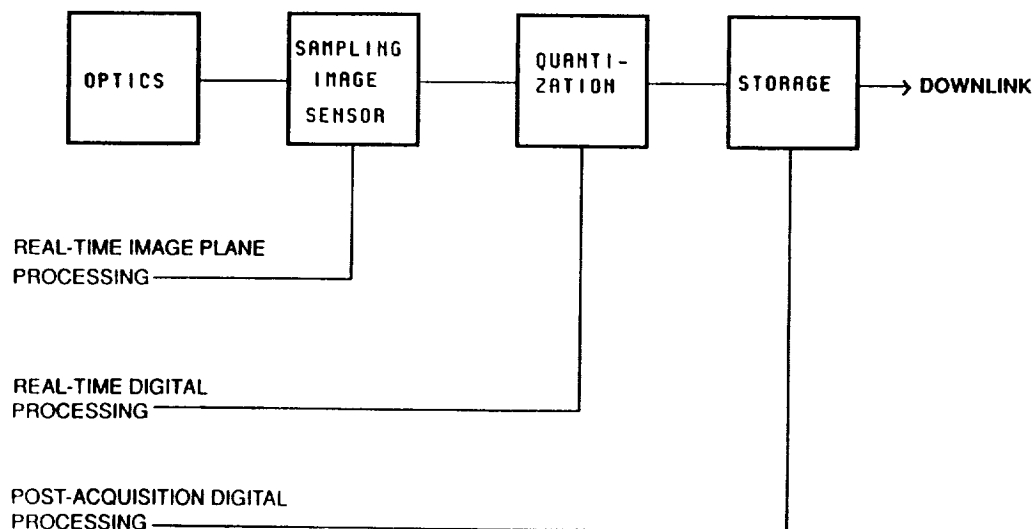
3. BAND PASS SFR

- 4. LOW PASS TEMPORAL FREQUENCY RESPONSE, INTEGRATING FOR .1 SEC
- 5. CONTOUR PERCEPTION
- 6. MOTION DEPENDENT SPATIAL RESPONSE
- 7. DIRECTIONAL SENSITIVITY - MORE SENSITIVE TO VERTICAL AND HORIZONTAL

• **DATA COMPRESSION BY FEATURE EXTRACTION**

II. THEORETICAL APPROACHES TO DATA COMPRESSION

• **OPPORTUNITIES FOR DATA COMPRESSION IN DATA PATH**



- **DATA COMPRESSION FOR LONG TERM HHVT SYSTEM MAY BE PERFORMED AT MULTIPLE LOCATIONS IN THE DATA PATH**

II. THEORETICAL APPROACHES TO DATA COMPRESSION

COLOR

- COMPOSITE SIGNAL CODING VS. COMPONENT CODING
- COMPONENT CODING HAS GIVEN BEST RESULTS IN THE LITERATURE
- BEST RESULTS WHEN YIQ COMPONENTS ARE USED INSTEAD OF RGB
Y = LUMINANCE SIGNAL I,Q = CHROMINANCE SIGNALS
- RGB TO YIQ CONVERSION IS STRAIGHTFORWARD AND LINEAR
- YIQ COMPONENTS ARE NEARLY UNCORRELATED, RGB ARE HIGHLY CORRELATED

III. PERFORMANCE CRITERIA

- PERFORMANCE IS HIGH CODING EFFICIENCY WITH HIGH FIDELITY
- WAYS OF EVALUATING CODING EFFICIENCY
 1. ACHIEVABLE COMPRESSION RATIO AT A GIVEN FIDELITY CRITERION
 2. UNCORRELATED DATA (FIRST GENERATION)
 3. MINIMAL DATA REPRESENTATION OF DESIRED FEATURE (SECOND GENERATION)
- WAYS OF EVALUATING FIDELITY
 1. **SUBJECTIVE OBSERVER**
IS THE OUTPUT IMAGE AESTHETICALLY PLEASING?
 2. **QUANTITATIVE**
IS THE ERROR MATHEMATICALLY MINIMIZED?
 - MEAN SQUARE $E = (f' - f)^2$
 - MAGNITUDE $E = |f' - f|$
 3. **FEATURE SPECIFIC**
ARE IMPORTANT FEATURES IN THE OUTPUT PROPERLY REPRESENTED?
 - EDGE AND CONTOUR INFORMATION
 - LUMINANCE / REFLECTANCE INFORMATION
 - COLOR INFORMATION
 - MOTION SEQUENCES

IV. COMPRESSION ALGORITHMS FOR HHVT

- **QUANTIFICATION OF USER REQUIREMENTS**
- **EACH USER'S VIDEO REQUIREMENTS CHARACTERIZED IN TERMS OF SIX PARAMETERS AND THEIR IMPORTANCE TO THE USER'S REQUIREMENTS**
- **SCORED FROM 0 (NOT IMPORTANT) TO 5 (VERY IMPORTANT)**
- **PARAMETERS CONSIDERED**
 1. **SPATIAL INFORMATION**
 - PLACEMENT AND SHARPNESS OF EDGES, CONTOURS
 - TEXTURE INFORMATION
 2. **TEMPORAL INFORMATION**
 - ACCURATE REPRESENTATION OF MOTION: SPEED AND DIRECTION
 3. **AESTHETIC APPEARANCE**
 - SUBJECTIVE EVALUATION BY HUMAN OBSERVER
 4. **LUMINANCE / REFLECTANCE INFORMATION**
 - CONTRAST
 - INTENSITY
 5. **SPECTRAL INFORMATION**
 - COLOR
 6. **IMAGE DYNAMICS**
 - ADAPTABILITY
 - NEED FOR COMPRESSION ALGORITHM TO VARY PERFORMANCE BASED ON SCENE ACTIVITY

IV. COMPRESSION ALGORITHMS FOR HHVT

- **QUANTIFICATION OF COMPRESSION TECHNIQUE PERFORMANCE**
 - EACH TECHNIQUE SCORED FOR EACH PARAMETER BASED ON HOW WELL IT PRESERVES THE PARAMETER WITHOUT INTRODUCING DEGRADATION
- **EACH TECHNIQUE SCORED AT COMPRESSION RATIO REQUIRED BY EXPERIMENT**
 - 0 = POOR PERFORMANCE
 - 5 = EXCELLENT PERFORMANCE
- **EVALUATING A GIVEN TECHNIQUE FOR A GIVEN EXPERIMENT**
 - FORM A REQUIREMENTS VECTOR (SIX ELEMENTS)
 - FORM A PERFORMANCE VECTOR (SIX ELEMENTS)
 - TAKE A DOT PRODUCT AND NORMALIZE

EXAMPLE:

$$\begin{array}{l} [5 \ 3 \ 3 \ 2 \ 0 \ 1] \\ \text{MAX} = 70 \end{array} \quad \begin{bmatrix} 5 \\ 2 \\ 2 \\ 1 \\ 1 \\ 5 \end{bmatrix} = 5(5) + 3(2) + 3(2) + 2(1) + 0(1) + 1(5) = 44$$

$44/70 = 63\%$
SCORE

- **THOSE COMBINATIONS RECEIVING HIGHEST SCORES WILL BE EVALUATED FURTHER**

IV. COMPRESSION ALGORITHMS FOR HHVT

• OTHER CONSIDERATIONS OF IMPORTANCE

1. TECHNIQUE COMPLEXITY

- SPEED
- WEIGHT
- COST
- DEVELOPMENT TIME
- POWER

2. SUSCEPTIBILITY TO CHANNEL ERRORS

- AFFECT ON IMPORTANT PARAMETERS
- LOCAL EFFECTS VS. AVERAGED EFFECTS
- RESTORABILITY

V. DATA COMPRESSION OVERVIEW

LOSSLESS CODING METHODS

• IMAGE IS FULLY RECOVERABLE GIVEN ERROR-FREE TRANSMISSION

EXAMPLES:

RICE ALGORITHMS (CODED DIFFERENCES)

RUN -LENGTH CODING

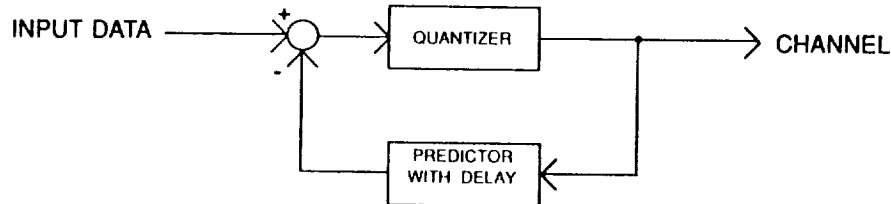
BIT PLANE CODING

CONDITIONAL REPLENISHMENT

V. DATA COMPRESSION OVERVIEW

• LOSSY PREDICTIVE CODING

- IMAGES ENCODED BY QUANTIZING THE ERROR BETWEEN THE PREDICTED VALUE OF A SUBPICTURE AND THE ACTUAL VALUE
- SUBPICTURES MAY BE INDIVIDUAL PELS OR VECTORS



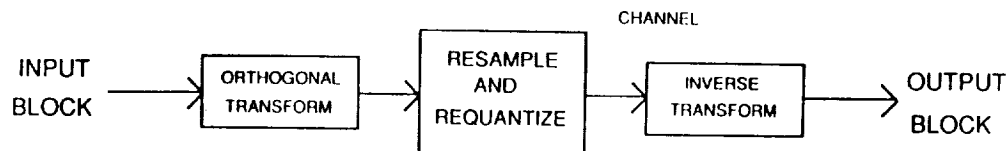
• EXAMPLES

- DPCM, VECTOR DPCM
- DELTA MODULATION
- MADE ADAPTIVE BY VARYING QUANTIZATION OR PREDICTION PARAMETERS WITH SCENE ACTIVITY

V. DATA COMPRESSION OVERVIEW

• TRANSFORM CODING

- LINEAR TRANSFORM (ORTHOGONAL BASIS SET) DESCRIBES SPATIAL "FREQUENCY" DOMAIN BEHAVIOR OF IMAGE

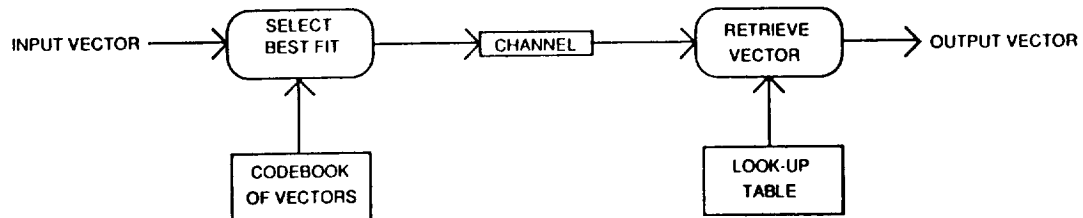


- LOW MAGNITUDE COEFFICIENTS IN "FREQUENCY DOMAIN" ARE UNDER QUANTIZED OR OMITTED DURING RESAMPLING AND REQUANTIZATION
 - THRESHOLD SAMPLING: SELECTIVE TRANSMISSION BASED ON COEFFICIENT MAGNITUDE (ADAPTIVE)
 - ZONAL SAMPLING: FIXED SAMPLING AND QUANTIZATION PATTERN DETERMINED A PRIORI FROM ANTICIPATED IMAGE STATISTICS (NON-ADAPTIVE)
 - ZONAL SAMPLING IS OFTEN MADE "CLASS-ADAPTIVE"
- EXAMPLES OF COMMONLY USED BASIS FUNCTIONS
 - KARHUNEN-LOEVE: OPTIMAL BUT VERY DIFFICULT TO IMPLEMENT
 - COSINE, FOURIER, SLANT, HADAMARD, HAAR: SUBOPTIMAL BUT EASIER TO IMPLEMENT

V. DATA COMPRESSION OVERVIEW

- VECTOR QUANTIZATION

- PARTITION THE IMAGE INTO BLOCKS TO BE TREATED AS VECTORS



- CODEBOOK DESIGNED A PRIORI WITH TRAINING DATA OR ADAPTIVELY TO MINIMIZE MEAN-SQUARE ERROR
- SEARCH ALGORITHMS FOR BEST FIT IN CODEBOOK CAN BE FULL (OPTIMAL) OR TREE-STRUCTURED (SUBOPTIMAL, BUT FASTER)
- DECODER IS A SIMPLE LOOK-UP TABLE
- LARGE CODEBOOKS GIVE BETTER OUTPUT, BUT COMPLEXITY RISES SHARPLY WITH CODEBOOK SIZE

V. DATA COMPRESSION OVERVIEW

- FEATURE EXTRACTION

- DETERMINE A PRIORI WHAT INFORMATION IS IMPORTANT IN THE IMAGE
- EXTRACT THIS INFORMATION UP FRONT AND DISCARD THE REST

- EXAMPLES:

- CONTOUR CODING
- SYNTHETIC HIGHS
- IDS
- DIRECTIONAL DECOMPOSITION
- CONTOUR TEXTURE CODING

- THESE TECHNIQUES OFFER THE HIGHEST COMPRESSION RATIOS

DATA COMPRESSION OVERVIEW

CATEGORY	LOSSLESS	LOSSY PREDICTIVE	TRANSFORM	VQ	FEATURE EXTRACTION
COMPRESSION FACTOR	2	8	16	20	100
LEAD TIME	NOW	NOW	NOW	1 YR	5 YRS
COMPLEXITY	LOW	LOW TO MODERATE	MODERATE TO HIGH	MODERATE TO HIGH	HIGH
DISTORTION EFFECTS	NONE	QUANTI- ZATION NOISE, LOSS OF DETAIL	LOSS OF DETAIL, BLOCKING	BLOCKING, ARTIFACTS	LOSS OF UNEXTRACTED INFORMATION
SENSITIVITY TO CHANNEL ERRORS	MODERATE TO HIGH	HIGH	MODERATE	MODERATE	VERY HIGH
CHANNEL DELAY	LOW	LOW	MODERATE	MODERATE	LOW
FLEXIBILITY	HIGH	MODERATE TO HIGH	HIGH	HIGH	LOW